PLANT AND ANIMAL LIFE IN THE PURIFICATION OF A POLLUTED STREAM

By C. ELSMERE TURNER, M.A., C.P.H.

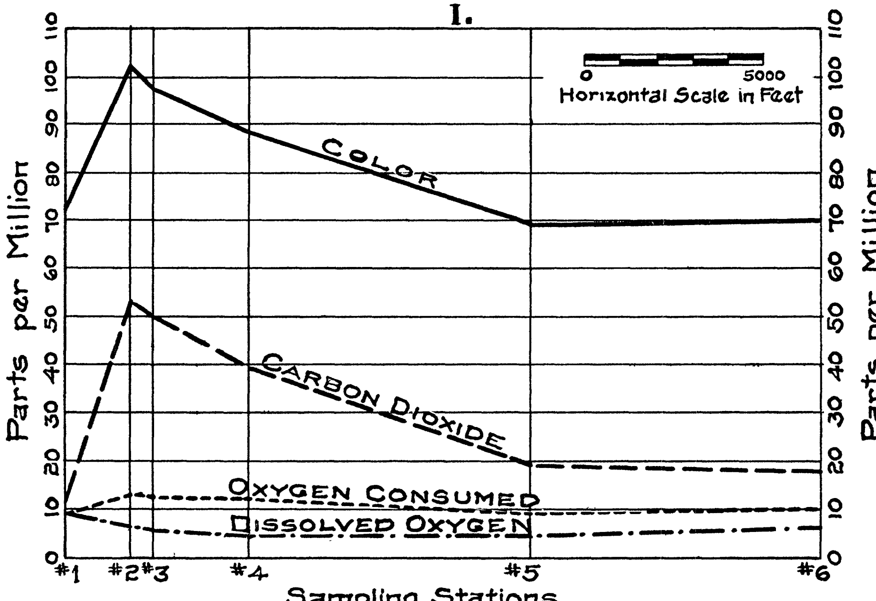
INSTRUCTOR IN THE DEPARTMENT OF BIOLOGY AND PUBLIC HEALTH, MASSACHUSETTS INSTITUTE OF TECHNOLOGY

RIVERS and other streams have always been resorted to by man for the disposal of his wastes. And yet unless greatly overtaxed they remain fairly clean. The problem here raised reminds one of that wonder of the ancients that all the rivers run into the sea and yet the sea is not full. What becomes of all the dirt and the street-wash and the sewage that find their way into our streams?

The "self-purification" of streams is an old and captivating phrase graphically describing a process which is patent even to a superficial observer. On the Merrimac, for example, Concord, Manchester and Nashua, important cities of New Hampshire, poured all their sewage into the noble river flowing past their doors, while Lowell, Mass., only sixteen miles below Nashua, did not hesitate to drink the water now again clear and bright, which reached the intake pipe of its city water works. More wonderful still, Lawrence, only nine miles below Lowell, drank directly from the same stream after the sewage of the 80,000 inhabitants of that city had been added to it. Alternating pollution and purification is the common characteristic of streams. The mechanism of pollution is obvious, but how about the process of purification? It was to throw further light if possible upon the self-cleansing of polluted streams, that the Sanitary Research Laboratory of the Massachusetts Institute of Technology carried on for two years an investigation of a small stream polluted by a relatively large quantity of partially purified sewage effluent which reaches it from slow sand filters.

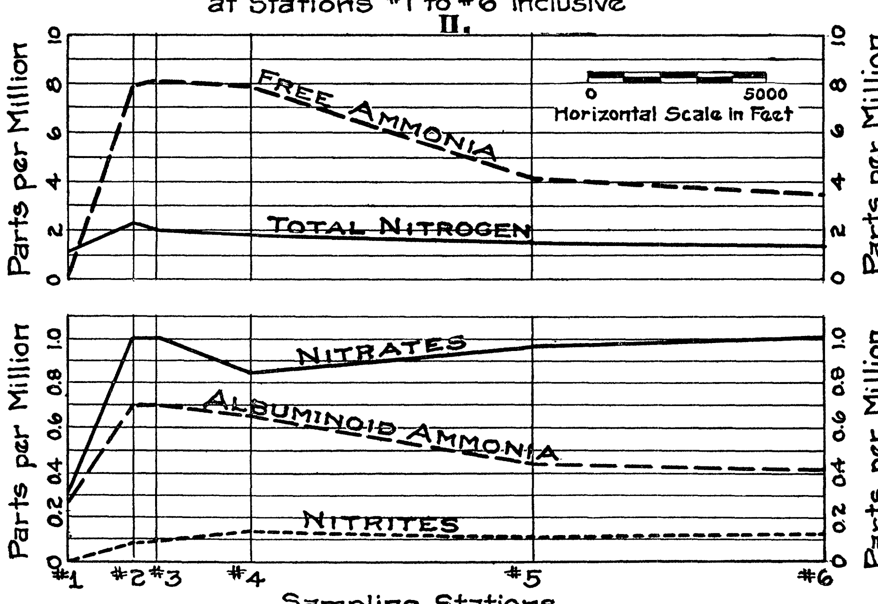
Whence comes the water of a normal brook or river? The answer is, partly from the atmosphere as rain or snow, partly from the earth's surface through tributary rills or brooklets, but largely from the ground upon which it has fallen, through which it is filtered, and from which it arrives comparatively pure from all but the smallest suspended matters. This ground water, however, does contain dissolved gases and salts together

I.



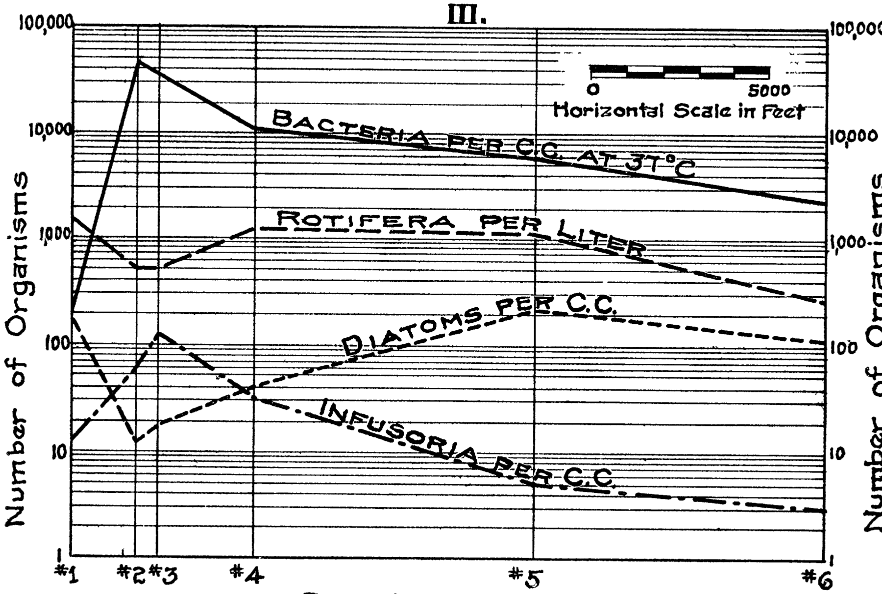
Yearly Averages of
COLOR, CO_2, O_2 CONSUMED AND DISSOLVED O_2
at Stations #1 to #6 Inclusive

II.



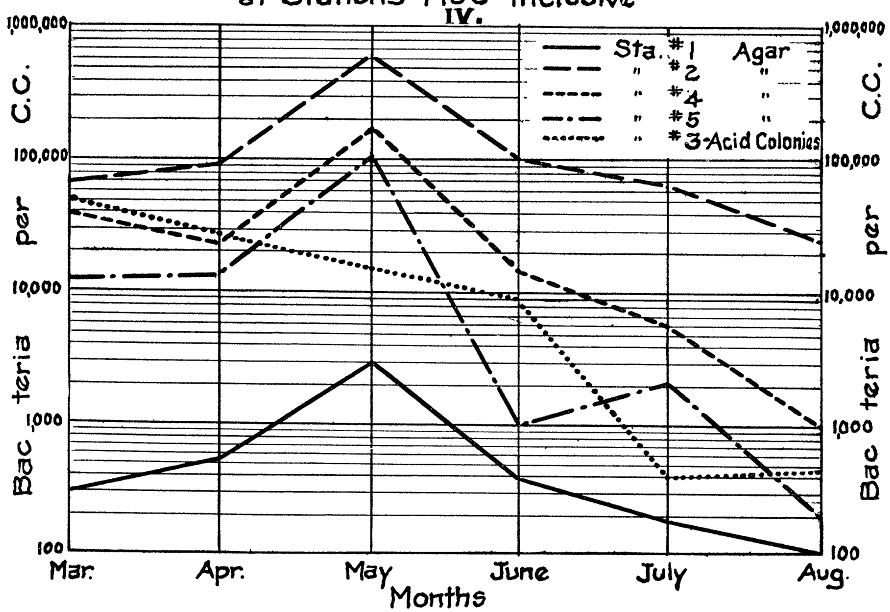
Yearly Averages of
NITROGEN AS FREE NH_3, ALBUMINOID NH_3, NITRITES,
NITRATES AND TOTAL N at Stations #1 to #6 Inclusive

III.



Sampling Stations
Yearly Averages of
ORGANISMS
at Stations #1 to #6 Inclusive

IV.

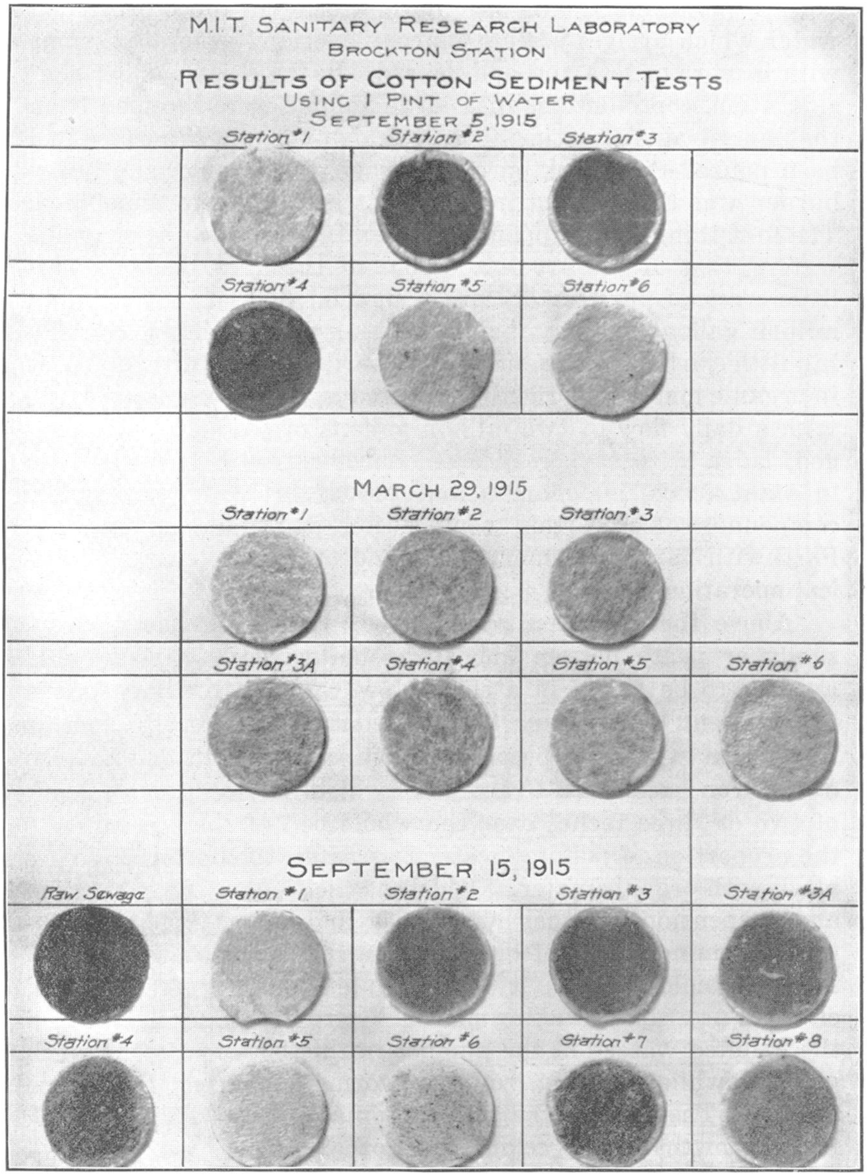


Average Monthly
TOTAL BACTERIA AND ACID COLONIES ON AGAR
for the 6 Months ending Sept. 1, 1915

with a small amount of organic matter. On the other hand, water which arrives after a journey overland generally brings with it more or less dirt and débris. In the stream under consideration, contributions of a large volume were received from the underdrains of artificial sand fields upon whose surface had been poured the Brockton city sewage. A strange and heavy burden was thus laid upon a quiet stream hitherto unpolluted. The first thing that happened was a mixture of two very unlike waters, that of the brook and that of the underdrains. This little creek of pure water with a summer flow of only one half million gallons per day, bright, clear, sweet smelling, containing little carbonic acid and few bacteria, poor in nitrates, poor in organic matter but rich in dissolved oxygen, becomes charged with a daily flow of two million gallons of water poor in oxygen, laden with carbon dioxide, burdened with bacteria, rich in plant foods, malodorous and full of broken-down organic compounds of uncertain composition and dubious ancestry. Forthwith various fermentations and other mysterious biological operations begin.

Above the Brockton sewage beds the brook has a clean, sandy or peaty bottom and the usual variety of plants and animals to be found in a clear New England brook. As the first effluent drains pour in their contribution, the bottom of the stream in summer becomes brown with a gelatinous growth of the iron bacterium, *Crenothrix*, which may occur to a depth of two or three inches over the whole bed of the stream. As the proportion of polluted water is greater, the bottom becomes black with organic material which has settled out from solution and suspension together with silica and other inorganic material forming a sort of "pollution carpet" or "false bottom" in which biological activity is very intense, and where chemical changes are rapidly taking place. There are many bacteria in the polluted water but the number in this bottom mud is much greater, while protozoa, rotifers, worms and insect larvæ also abound. The sides of the stream in many places are gray with furry growths of the colonial protozoa, *Carchesium*.

Throughout the regions where this false bottom is present —and it extends for three fourths of a mile below the filter beds —there may be seen large patches of the red worm, *Tubifex tubifex*. The countless individuals making up these colonies of bristle worms, so typical of pollution, remain with their heads in their burrows, the tails, like a red flag of pollution, waving in the water above them in search of oxygen. They quickly disappear into their holes at the slightest disturbance



in the water such as might be made by the approach of a fish, for it must be noted that higher animals are not driven away by the amount of pollution here present. Minnows are frequently seen in this part of the stream, often nibbling at the furry growths of *Carchesium* mentioned above. In the spring suckers are to be found here and occasionally brook trout or brook pickerel make their appearance. They are, however,

more abundant in the stream below or above the area of greatest pollution. Snapping turtles, water snakes and the green frog, *Rana clamata,* are frequently seen and the valley of the brook contains an abundance of bird life including wild ducks, crows, robins, bobolinks, blackbirds, grackles and sparrows.

By far the most conspicuous of the insect larvæ in this region of abundant food material is the "blood worm" or larva of the midge, *Chironomus decorus,* which is one of the most efficient scavengers of this type of stream bottom. The mature insect is about the size of the mosquito and in appearance bears a close resemblance, although fortunately its habits are much less objectionable. In this species there is no irresistible impulse to gorge itself with blood and usually the mature form never feeds. The eggs are laid in rows in a gelatinous sack which is attached to some object at the surface of flowing water. Each sack contains 1,200 to 1,500 eggs and so numerous are they that a partly submerged railroad tie was found to furnish a hatching place for over 300,000 midges. The larva is hatched as a white wiggler nearly 1 mm. long which soon settles to the bottom and spends most of its time in eating, growing in three or four days to one fourth of an inch in length and taking on a pink color which soon develops into a brilliant red. At this time the larva begins to make a case for itself by gluing together the material about it with a gelatinous substance from its salivary glands. In many places on the muddy and soft stream bottom, these little mounds, each with an opening at the top, number four or five hundred per square foot. A 30 c.c. sample of bottom mud collected to a depth of 2″ in August, 1914, contained 130 of these larvæ. The larval period lasts from several days to several weeks depending upon the temperature, then follows a brief pupal stage in which the insect undergoes metamorphosis and at the end of which the pupa, which is also active, rises to the surface. The pupal case is split along the back, the imago emerges, rests for a minute on the floating pupal case and then flies away. If the good fortune by which it escaped fish and predatory insects continues and it is able to avoid the numerous dragon flies and other enemies for a day or two it reproduces and dies. From the omnivorous habits of the larvæ, their value as food for fish, and the number of mature insects which leave the water entirely, it is obvious that *Chironomus* is an important factor in the removal of organic matter.

Of the great variety of insect larvæ found in this region, mention may here be made of only one other, the larva of the

Midsummer view of the Stream from near Station 2. This shows the part of the stream which is receiving pollution from the sand sewage-filter beds. Note that the stream is somewhat swifter here and the vegetation on the banks is most luxuriant. From photo taken July 21, 1915.

club-footed gnat, *Ptychoptera clavipes.* These brown air-breathing larvæ have the same habitat as do the blood worms, although they are not as numerous or as important from the standpoint of stream purification. The first generation appears about the middle of March and from that time they are abundant until late fall. Both the larval and pupal stages are

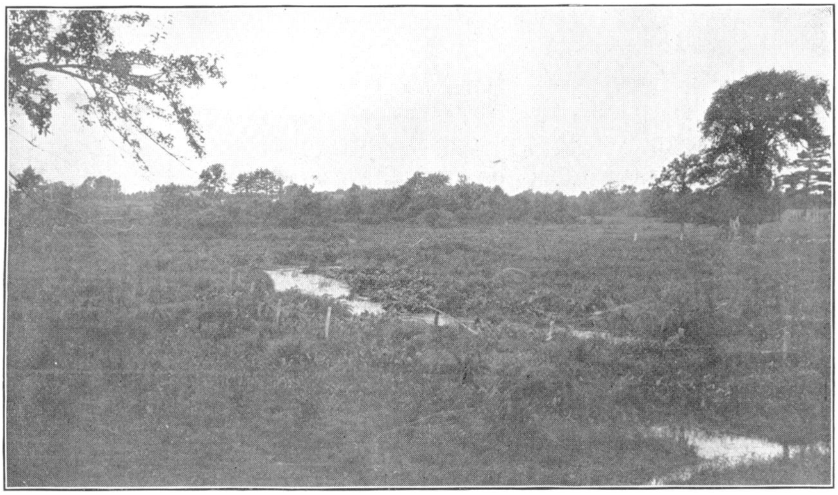
A corresponding view on January 26, 1916, showing where some of the sewage effluent drains enter the stream, as well as the appearance of the banks in winter and the increased volume of water.

to be found in relatively shallow and quiet water with the elongated breathing tubes reaching to the surface.

It must not be concluded that plant life is absent from this region. To be sure the variety of higher plants disappears at the point of pollution, but one by one these plants reappear as the pollution is reduced, so that the region three quarters of a mile below the filter beds contains the rankest growth of water plants to be found in any part of the stream. Throughout the summer and until late fall they choke the stream in this region, reducing the velocity of the current, furnishing shelter to a wide variety of smaller animal and plant forms, supplying oxygen to the stream, and acting as a contact filter upon which may settle out suspended and colloidal substances. So efficient is this filter that attempts to measure the velocity of stream flow by adding a coal-tar dye to the water were completely frustrated.

In the masses of these plants as well as upon the stream bottom, there may be found innumerable snails and small crustacea. Upon one occasion fifty snails were gathered by one scoop with the two hands at a point one half a mile below the filter beds. The Isopod, *Asellus,* which is present in all parts of the stream, is so abundant here that as many as twenty may often be seen upon a square foot of the stream bottom, while a handful of water grass or pond weed may contain twice this number. Smaller crustacea, the water fleas, are also abundant, their presence being correlated with that of the simple green algæ. In a pool a short distance below the filter beds the water is green in summer with *Chlamydomonas* and *Euglena*. At such times the Daphnia-like form, *Simocephalus,* is so abundant that even the surface water contains more than one thousand per liter. In all these the digestive tract is filled with the green flagellates which appear to constitute the chief food. Special chemical tests show that there is a daily seesaw between the oxygen dissolved in the water and CO_2 under these conditions. The former goes up continually through the daytime under the stimulation of sunlight upon the chlorophyll-bearing flagellates, and the latter goes up continually through the night because of animal activity, the total volume of oxygen in the two gases remaining practically constant. In the fall when these water fleas are most abundant myriads of *Hydra* are found throughout the higher plants.

This in brief is the picture of the stream as we find it through the summer months, when it teems with an activity so



This view, looking north near Station 4, July 21, 1915, shows how completely the higher aquatic plants fill this part of the stream in summer. Station 4 is located at a point in the very center of the picture.

intense that the term "living earth" as applied to the bottom of a polluted stream takes on a new significance. We are better able to understand the intensity of this biological digestive process when we add to our picture of these larger forms a measure of the microscopic organisms to be found in the water and some measure of the chemical process which is here carried on. The accompanying diagrams show the quantity of chemical substances and microorganisms in the water

A corresponding view, January 26, 1916, shows how differently this same region appears under winter conditions and high stream flow.

at various points, Station 1 being on the unpolluted stream above the filter beds and Station 2 at the point of greatest pollution. The distance from Station 2 to Station 3 is 980 ft., to 3a it is 2,000 ft., to 4 it is 3,650 ft., to 5 it is 11,580 ft. and to 6 it is 19,700 ft. The discussion thus far has been confined to the area between Stations 2 and 4.

Chemical changes are also graphically shown. By careful measurements and computations from our chemical analyses, it was found that in summer the average reduction in total organic nitrogen, as measured by the Kjeldahl process, in the first three quarters of a mile below Station 2 was as great as 39 lbs. per day. If we were to consider this upon the basis of protein consumption, it would mean that the equivalent of more than 150 lbs. of beefsteak is digested daily by the small stream in traveling this distance.

Standard chemical and bacteriological methods were used in making the weekly analysis from which the averages here graphically represented were computed but the method of securing the biological data may require some explanation. It was soon learned that quantitative determinations of micro-organisms according to the Sedgwick-Rafter process were of little value if the samples were collected from the surface water. The forms thus found were the floating organisms which had been brought down from up the stream instead of the forms "working" at that point. Accordingly the bottom of the brook was disturbed across its entire breadth by means of a garden rake and a sample from the clouded water thus produced collected in a 500 c.c. wide-mouthed bottle at a depth of 6 inches below the surface. Naturally these samples were somewhat widely varying but since they were collected near the surface they can not overestimate the number of organisms and the graphs made from the yearly average really show the effect of pollution upon the smaller plant and animal life of the stream.

A word should be said about this region in winer. Early in December the higher plants disappear. The volume of the stream increases to ten or occasionally twenty million gallons per day, the nitrification of the sewage in passing through the sand filters is less complete and the whole stream presents a markedly different appearance, as may be seen from the accompanying photographs. At about this time, the water mould, *Leptomitus,* appears near the effluent drains and within a couple of weeks covers the bottom and sides of the stream throughout the first three quarters of a mile of its flow. There are literally tons of the mould present, which soon changes

from its fleecy white appearance to a dirty gray color because of the accumulation of dirt and organic matter which has settled upon it from the polluted water. This is a new pollution carpet which nature has spread over the bottom of the swollen stream for the winter season. Among the threads of the mould intense biological activity takes place. As many as 400,000 bacteria per c.c. are present and the protozoa (*Colpidium, Chlamydomonas, Euglena viridis, Euplotes*) total 125 per c.c., while *Asellus,* midge larvæ and naid worms are abundant. The stream overflows the meadows, and over these acres of flooded marsh land, *Leptomitus* occurs in abundance. The water shows little or no improvement in this region in winter beyond that directly due to dilution, and because *Leptomitus* is continually breaking down and flowing along with the current, some samples in early spring show even more organic matter three quarters of a mile below the filter beds. At this season the meadows become covered with filamentous green algæ (*Conferva* and *Spirogyra*) which grow with *Leptomitus* and gradually supplant it. The fungus is figuratively driven up the stream and into the mouths of the effluent drains to emerge again the following winter. The algæ appear first at some distance down the stream and slowly work their way toward the point of pollution. As the water subsides, these growths are left as a black deposit on the soil resembling sewage scum in appearance. With the arrival of warm weather the filter beds become more efficient, the zone of greater pollution which is measured by the presence of *Leptomitus* is shortened, the biological activity of the stream increases and summer conditions return.

We have as yet considered only the first three quarters of a mile of the polluted stream. At this point a small effluent stream joins the one under observation and during the summer months the self-purification mentioned above is so important and complete that below this point, from a biological point of view, the stream is comparatively normal except perhaps that more plants are present because of the greater amount of plant food. The false bottom no longer persists and to the casual observer nothing unusual would be noted either in the water or plant and animal life.

Samples were taken regularly at points one mile and two miles below the juncture of the two streams with results which appear in part in the accompanying diagrams. The chemical studies reveal the presence of distinct pollution, but it is clear that biological activities are less intense and that, because of

this, chemical changes are much slower. In the winter when the purification is much slower and depends largely upon the factor of dilution, these lower regions of the stream are in a worse condition. But *Leptomitus* is never found growing below the juncture of the two streams except for such small masses as may be carried down by the current and persist temporarily. The chief interest, therefore, attaches itself to the more intense digestive process above described, showing how nature lends her assistance to the sanitary engineer, enabling him to carry the sewage effluent of the shoe manufacturing city of 65,000 people into a tiny brook only six or eight feet wide.

The complete details and conclusions of a two years' study are contained in the original report, but some of the general facts, without special reference to quantitative results, may be briefly stated. It is obvious that the biological factors of stream purification are much more important than the strictly chemical and physical factors. The activities during the summer months were sufficiently intense to take care of the burden being placed upon the stream at that time and also to remove the load of pollution which the winter had left. Certain organisms are characteristic of an unpolluted stream. Others are characteristic of pollution and by their presence and numbers indicate the intensity of biological activity. Some forms like rotifers and certain green algæ may be present in either polluted or unpolluted water and their correlation with each other and various plants and animals must be understood to appreciate their significance.

The organic matter, introduced with a sewage effluent, results in the increase of organisms in a cycle beginning with bacteria and ending with the higher forms, each type of animal appearing with a definite food supply. A comparison of this investigation with studies made upon other streams and grosser types of pollution shows that the smaller, shallower and more nearly stagnant the body of water with which the pollution is mixed and the more nitrified and clarified the effluent, the more rapid is the succession of zones of higher animal life and the more complete the process of purification.